MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2016/2017

EME4016 – HEAT TRANSFER

(ME)

11 OCTOBER 2016
9.00 a.m. - 11.00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question Paper consists of seven pages including the cover page.

2. Answer ALL questions. Each question carries 25 Marks and the distribution of the Marks for each question is given in brackets [ ].

3. Write all your answers in the Answer Booklet provided.

Question 1

(a) In a heating process, both sides of a 20-mm thick rubber sheet are heated in a steam chamber for which both sides of the rubber sheet are maintained at T_s =200 °C. The rubber sheet is taken from an initial temperature of T_i =25 °C to a midplane temperature of 150 °C. Rubber has a thermal conductivity of k = 0.14 W/m·K and a thermal diffusivity of α= 6.35 x 10^{-8} m^2/s.

(i) Estimate the time taken for the midplane temperature to achieve 150 °C. **[6 marks]**
(ii) Approximate the largest temperature gradient in the rubber sheet at the above time. **[9 marks]**

Note: The one-term approximation for a plate of thickness L, subjected to constant surface temperature at both sides, is given as

$$\theta^* = \theta_o^* \sin(\pi x^*),$$

where θ_o^* represents the middle plane temperature of the plate and

$$\theta_o^* = \frac{4}{\pi}\exp(-\pi^2 Fo).$$

The dimensionless variables are defined as $\theta^* = \frac{T - T_s}{T_i - T_s}$, $x^* = \frac{x}{L}$ and $Fo = \frac{\alpha t}{L^2}$.

The coordinate $x^* = 0$ corresponds to the left side of the rubber sheet.

(b) A large plate at uniform temperature T_i = 200 °C is suddenly quenched by immersing it in a liquid bath of temperature T_∞= 20 °C. Heat transfer to the liquid is characterized by a convection coefficient h= 100 $W/m^2 \cdot K$. It is given that the plate has a density of ρ = 2770 kg/m^3 and specific heat of c_p = 875 J/kg ·K.

(i) If x =0 corresponds to the midplane of the plate and the thickness of the plate is denoted as $2L$, what is the heat flux at x =L at t =0 ? **[4 marks]**
(ii) For a plate of thickness 20 mm, determine the amount of energy per unit surface area in J/m^2 that is transferred to the bath over the time required to achieve steady state condition. **[6 marks]**

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Question 2

(a) The spectral transmissivity of a glass cover used in a solar collector is given as:

$$\tau_\lambda = \begin{cases} 0.9 & 0 < \lambda < 3\,\mu m \\ 0 & \lambda > 3\,\mu m \end{cases}$$

The solar irradiation on the glass cover is 950 W/m^2 and the absorber plate, which can be assumed as a blackbody, is kept at 340 K. Assume that the sun emits as a blackbody at 5800 K.

(i) Determine the solar irradiation on the absorber plate. **[7 marks]**
(ii) Evaluate the transmissivity of the glass cover for radiation emitted by the *absorber plate*. **[6 marks]**

Note: You may need to refer to Appendix 1.

(b) A long furnace has a cross-sectional shape of a right-angled triangle with two of its sides equal in length. A *uniform heat flux* of 800 W/m^2 is supplied from the base surface having an emissivity $\varepsilon_1 = 0.8$ while the side surfaces with emissivities 0.5 are kept at 500 K. Neglecting end effects, determine the temperature of the base surface. **[12 marks]**

Take the Stefan-Boltzmann constant to be 5.67×10^{-8} W/m^2·K^4.

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Question 3

A pharmaceutical fluid is heated from 25 °C to 75 °C as it moves at 0.2 m/s through a straight thin-walled stainless steel tube of 12.7 mm diameter and 10-m in length. A uniform heat flux is applied to the outer surface of the tube. Fluid properties may be approximated as: ρ = 1000 kg/m^3, c_p = 4000 J/kg ·K, μ = 2 x 10^{-3} kg/s·m, k= 0.8 W/ m·K, and Pr = 10.

(a) Determine the heat flux applied to the outer surface of the tube. **[6 marks]**
(b) The fluid enters the tube with a fully developed velocity profile, and a uniform temperature profile, what is the surface temperature at the tube exit ? **[14 marks]**
(c) Reason and comment on the temperature difference between the surface and the fluid at half length of the tube. **[5 marks]**

Note:

1. A laminar flow is thermally fully developed if $\frac{L}{D} > 0.05 RePr$.

2. Convection correlations for flow in a circular tube are:

Correlation		Conditions
$Nu_D = 4.36$	(8.53)	Laminar, fully developed, uniform q_s''
$Nu_D = 3.66$	(8.55)	Laminar, fully developed, uniform T_s
$\overline{Nu}_D = 3.66 + \frac{0.0668(D/L)Re_D Pr}{1 + 0.04[(D/L)Re_D Pr]^{2/3}}$	(8.56)	Laminar, thermal entry (or combined entry with $Pr \gtrsim 5$), uniform T_s
or		
$\overline{Nu}_D = 1.86\left(\frac{Re_D Pr}{L/D}\right)^{1/3}\left(\frac{\mu}{\mu_s}\right)^{0.14}$	(8.57)	Laminar, combined entry, $0.6 \lesssim Pr \lesssim 5$, $0.0044 \lesssim (\mu/\mu_s) \lesssim 9.75$, uniform T_s
$Nu_D = 0.023 Re_D^{4/5} Pr^n$	(8.60)[c]	Turbulent, fully developed, $0.6 \lesssim Pr \lesssim 160$, $Re_D \gtrsim 10{,}000$, $(L/D) \gtrsim 10$, $n = 0.4$ for $T_s > T_m$ and $n = 0.3$ for $T_s < T_m$
or		
$Nu_D = 0.027 Re_D^{4/5} Pr^{1/3}\left(\frac{\mu}{\mu_s}\right)^{0.14}$	(8.61)[c]	Turbulent, fully developed, $0.7 \lesssim Pr \lesssim 16{,}700$, $Re_D \gtrsim 10{,}000$, $L/D \gtrsim 10$
or		
$Nu_D = \frac{(f/8)(Re_D - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}$	(8.62)[c]	Turbulent, fully developed, $0.5 \lesssim Pr \lesssim 2000$, $3000 \lesssim Re_D \lesssim 5 \times 10^6$, $(L/D) \gtrsim 10$

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Question 4

(a) An aluminum fin, of length L=7.5 cm, protrudes from a wall. The fin has a rectangular cross section of thickness t = 3.0 mm and width W= 30 cm; its thermal conductivity is k = 200 W/m·K. The base of the fin is maintained at 300 °C, and the ambient temperature is 50 °C. The heat transfer coefficient between the fin and the ambient is h = 10 W/m^2·K. *Assume that the heat transfer from the tip is negligible.*

(i) State the temperature distribution across the fin, you may leave your answer in symbols. **[3 marks]**

(ii) Calculate the heat loss from the fin. **[6 marks]**

Note: You may need to refer to Appendix 2.

(b) In a textile manufacturing plant, the waste dyeing water (c_p = 4295 J/kg·K) at 80 °C is used to preheat fresh water (c_p = 4190 J/kg·K) from 10 °C to 50 °C at the *same mass flow rate* in a double-pipe counter flow heat exchanger. The heat exchanger has a rate of heat transfer of 35 kW and overall heat transfer coefficient of 625 W/m^2·K.

(i) Calculate the mass flow rate of each fluid stream. **[5 marks]**

(ii) Determine the exit temperature of the dyeing water. **[5 marks]**

(iii) What is the required surface area of the heat exchanger? **[6 marks]**

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APPENDIX 1: Numerical values of the function $F(0 \rightarrow \lambda)$

λT (μm · K)	$F_{(0 \rightarrow \lambda)}$	λT (μm · K)	$F_{(0 \rightarrow \lambda)}$
200	0.000000	9,500	0.903085
400	0.000000	10,000	0.914199
600	0.000000	10,500	0.923710
800	0.000016	11,000	0.931890
1,000	0.000321	11,500	0.939959
1,200	0.002134	12,000	0.945098
1,400	0.007790	13,000	0.955139
1,600	0.019718	14,000	0.962898
1,800	0.039341	15,000	0.969981
2,000	0.066728	16,000	0.973814
2,200	0.100888	18,000	0.980860
2,400	0.140256	20,000	0.985602
2,600	0.183120	25,000	0.992215
2,800	0.227897	30,000	0.995340
3,000	0.273232	40,000	0.997967
3,200	0.318102	50,000	0.998953
3,400	0.361735	75,000	0.999713
3,600	0.403607	100,000	0.999905
3,800	0.443382		
4,000	0.480877		
4,200	0.516014		
4,400	0.548796		
4,600	0.579280		
4,800	0.607559		
5,000	0.633747		
5,200	0.658970		
5,400	0.680360		
5,600	0.701046		
5,800	0.720158		
6,000	0.737818		
6,200	0.754140		
6,400	0.769234		
6,600	0.783199		
6,800	0.796129		
7,000	0.808109		
7,200	0.819217		
7,400	0.829527		
7,600	0.839102		
7,800	0.848005		
8,000	0.856288		
8,500	0.874608		
9,000	0.890029		

$$F(0 \rightarrow \lambda) \equiv \frac{1}{\sigma T^4} \int_0^{\lambda} E_{\lambda,b}\, d\lambda$$

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APPENDIX 2: Temperature distribution and heat loss for fins of uniform cross section

Temperature distribution and heat loss for fins of uniform cross section

Tip Condition ($x = L$)	Temperature Distribution θ/θ_b	Fin Heat Transfer Rate q_f
Convection heat transfer: $h\theta(L) = -kd\theta/dx\|_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$
Adiabatic $d\theta/dx\|_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$	$M \tanh mL$
Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$
Infinite fin ($L \to \infty$): $\theta(L) = 0$	e^{-mx}	M

$\theta \equiv T - T_\infty$ $\quad m^2 \equiv hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\theta_b$

End of Paper